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ePATHS - electrical PCM Assisted Thermal Heating System

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Delphi Automotive Systems

June 10, 2015

Project ID # VSS136

ePATHS Overview

Timeline

- Start Date – Oct. 1, 2013
- End Date – Dec. 31, 2016
- Percent Complete – 45%

Budget

- Total project funding: $3.48M
  - DOE share: $1.74M
  - Contractor share: $1.74M
- Funding received in BP-1: $1.1M
- Funding for BP-2: $1.4M

Note: BP-1 (4Q13 + CY2014 + Jan & Feb 2015)

BP2 (March – December 2015)

Barriers & Targets

- EV cold weather range +20%
- Phase Change Material (PCM) latent capacity +50%
- Vehicle integrated PCM heating and control system

Team/Partners

- *Ford Motor Company*
  - Vehicle reqm'ts & controls integration
- *Oak Ridge Nat'l Lab*
  - Simulation, design & cert. testing
- *Entropy Solutions*
  - High capacity PCM development
- *Project Lead - Delphi*

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Relevance: Support VTP Efforts

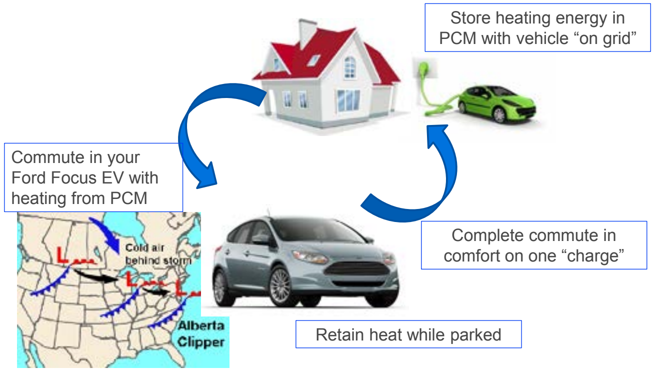
- DOE Vehicle Technologies Program (VTP)
  - Reduce Petroleum usage and GHG emissions…
  - Requires ”…new and more fuel efficient vehicle technologies.”
- EV-Everywhere Grand Challenge
  - ‘… produce electric vehicles that are as affordable for the average American family as today’s gas-powered vehicles within the next 10 years (by 2022). “
  - Driving range influences consumer acceptance
- AOI-11 Advanced Climate Control Auxiliary Load Reduction
  - Advanced HVAC Technologies: increase range
  - “…innovative and unique heating…” using phase change materials

FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

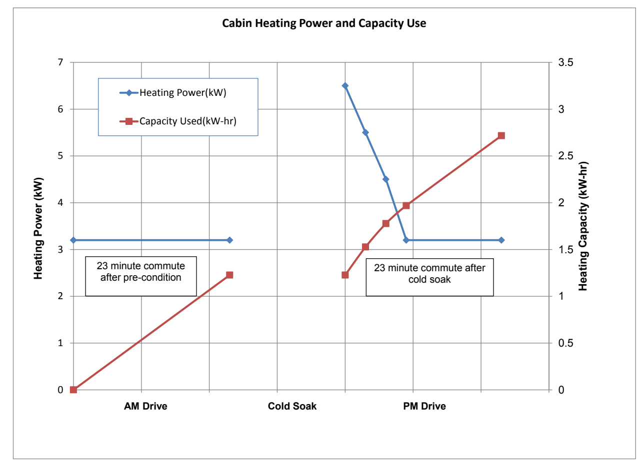
FOA DE-0000793

Relevance

- Extend GCEV electric range >20% by reducing or eliminating the auxiliary heating load from the vehicle battery @-10°C
  - Develop "hot" PCM with >50% increase in latent heat capacity for industry application
  - Develop simulation and optimization code for system and components
  - Seamless vehicle integration with smart charging and discharging control
  - Demonstrate performance and establish commercial viability



Typical Commute Usage Cycle



Representative Heating Demand

Milestones - Project Execution

	Start	Finish
• Budget Period 1 –Design/Development	10/1/13	2/28/15

- First Go / No-Go

Milestone	Type	Description
System Component Specifications Complete	Technical	The System and component specifications will be complete
Development Level Design Complete	Go/No Go	Development Level designs for the system and components completed and ready for build.

BP-1 Milestones Accomplished

	Start	Finish
• Budget Period 2 – Development/Demonstrate	3/1/15	12/31/15

- Second Go / No-Go

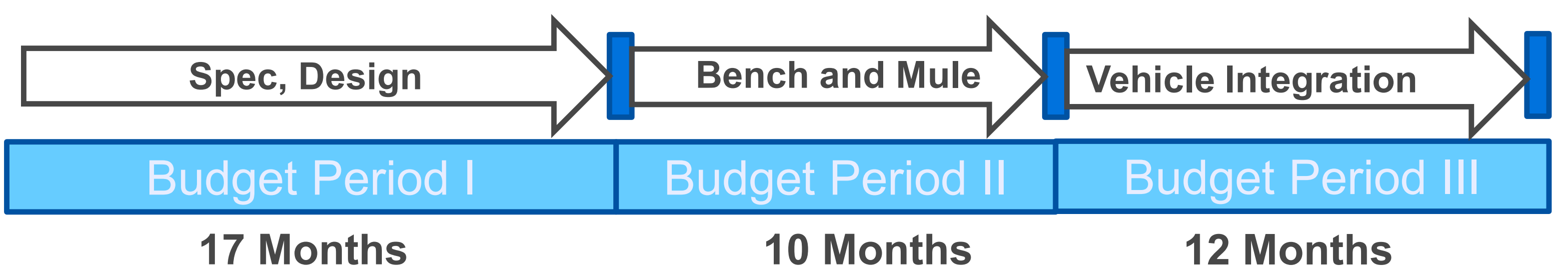
Milestone	Type	Description
Thermal Energy Storage Demonstration	Go/No Go	Analysis validates that the system approach results in at least 20% increase in electric drive range vs. the baseline vehicle

	Start	Finish
• Budget Period 3 – Integration/Validation	1/1/16	12/31/16

Milestone	Type	Description
Vehicle Integration System Complete	Technical	Integrated system testing completed and performance targets are achieved
Vehicle Testing Complete	Technical	Vehicle testing complete including evaluation of Thermal Performance, Charging Process, and Range Improvement.

Approach/Strategy

- **Technical Approach**
  - Working with OEM Partner Ford to identify vehicle level technical requirements (Ford, Delphi, ORNL) and range test protocol
  - Based on vehicle requirements, establish system and components specification (Team)
  - Working with ORNL to establish system and components modeling-analysis capability (ORNL, Delphi)
  - Establish system and components design, using analysis tool to achieve optimization (Delphi, ORNL)
  - Establish controls hardware and software strategy (Delphi, Ford)
  - Build and test bench system for proof of concept (Delphi, ORNL)
  - Final system build and vehicle integration
  - Perform range certification test at Delphi/ORNL
- **Milestones**



Technical Accomplishments and Progress
System and Components Specifications

- **Objective**
  Develop a Vehicle and System level Specification to define the vehicle interface and operating parameters for the ePATHS system in a light-duty BEV automotive vehicle.

- **Accomplishments and Progress**
  Vehicle, System and Component Specifications Completed

System/Component	Spec. Document Name	Spec. Status	Develop. Design Status
Vehicle and System	SD18-XXX- ePATHS - SystemLevelSpecs 05FE15	Complete ☑	N/A
Controls Specification	SD18-XXX-ePATHS Control Specs 19FE15.docx	Complete ☑	N/A
PCM Heat Exchanger	SD18-XXX ePATHS PCM HX Specification.docx	Complete ☑	Complete ☑
PCM HX Insulaltion	Sd18-XXX ePATHS PCM HX Insulation Specification.docx	Complete ☑	Complete ☑
HVAC Heater	SD18-XXX ePATHS Heater.docx	Complete ☑	Complete ☑
PCM Charging Heater	SD18-XXX ePATHS Charging Heater Specification.docx	Complete ☑	Complete ☑
PCM Material	SD2-XXX ePATHS PCM Spec 07OC14.doc	Complete ☑	N/A
Coolant Pump	Buehler Motor Brushless Pump 50W Technical Spec.pdf	Complete ☑	N/A
Coolant Valve	TGK Coolant Valve Specification.pdf	Complete ☑	N/A

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Technical Accomplishments and Progress
Confirmation Testing Design

- **Charging Time Test**
  - Charge at 15 °C (garage temperature) until fully charged, as indicated by PCM temperature of 120 °C and the coolant out temperature should be above 120 °C. Keep track of charging time and compare with performance spec.
- **Soak And Warm-up Tunnel Test**
  - Perform Delphi or Ford soak and warm-up test. (Reference Delphi or Ford test procedure)
- **Vehicle Range Test**
  - Target to run a steady-state test to end of range and a drive cycle to end of range at -10C.
  - Use SAE J1634 and FTP20 for the drive cycle tests.

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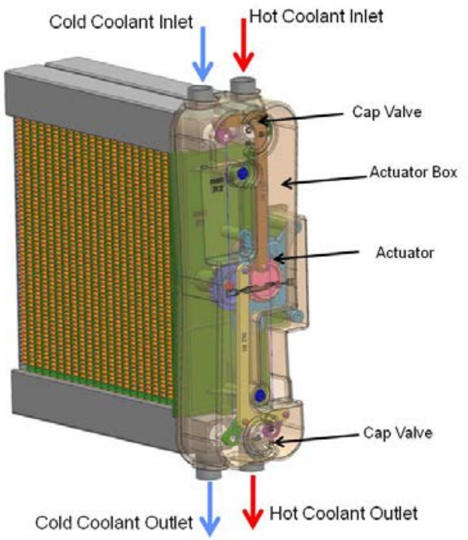
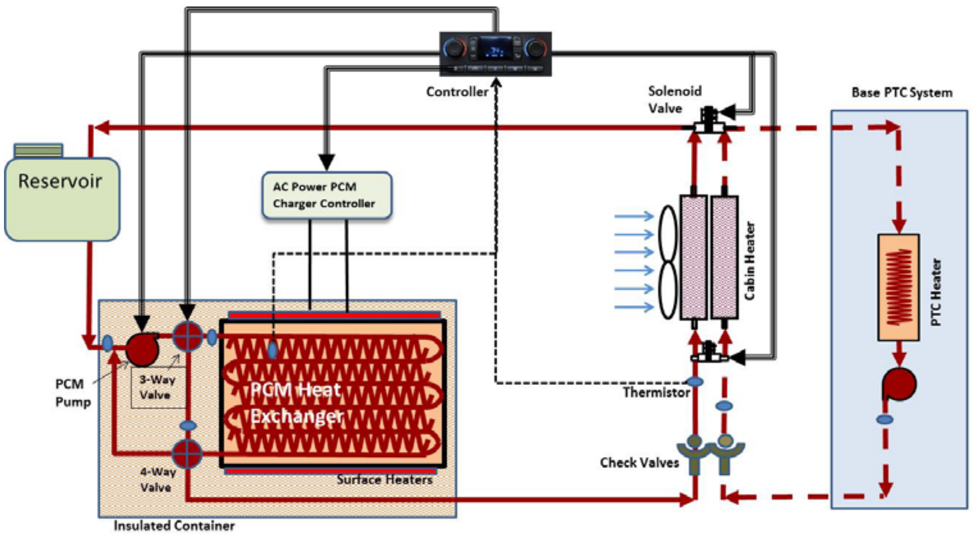
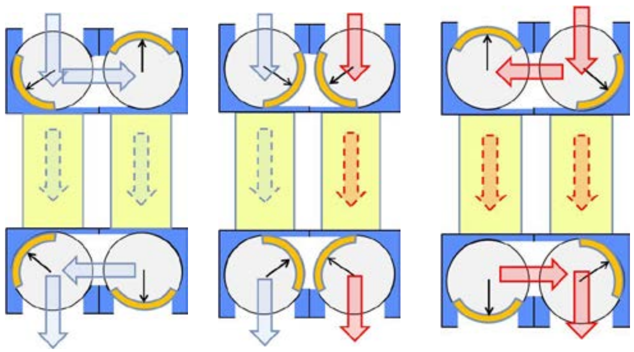
Technical Accomplishments and Progress
System Design and Architecture

- System architecture considers charging, discharging, heat loss reduction, and maximum heat extraction from PCM
- CapHX incorporated into system design
  - Able to extract PCM energy to near 0 °C

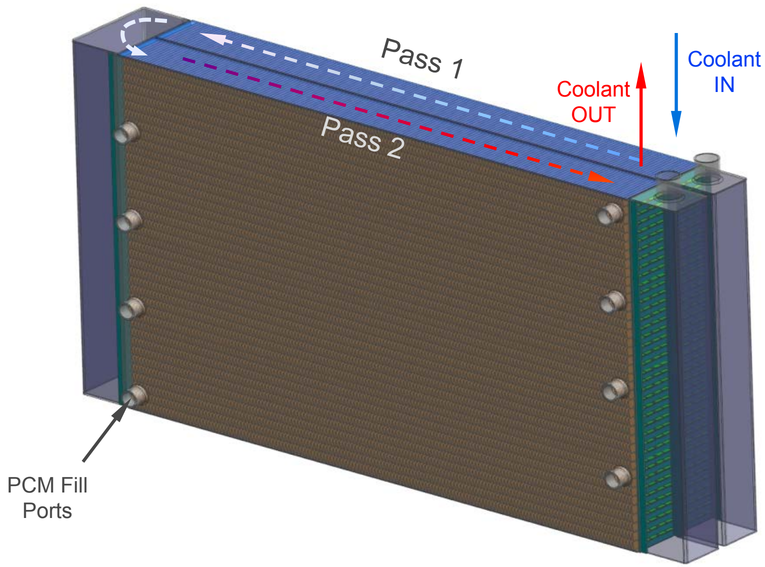




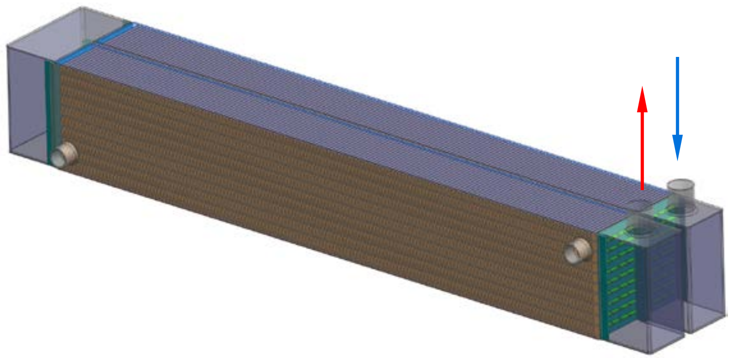


Technical Accomplishments and Progress

PCM Heat Exchanger Design



Full-size ePATHS Heat Exchanger

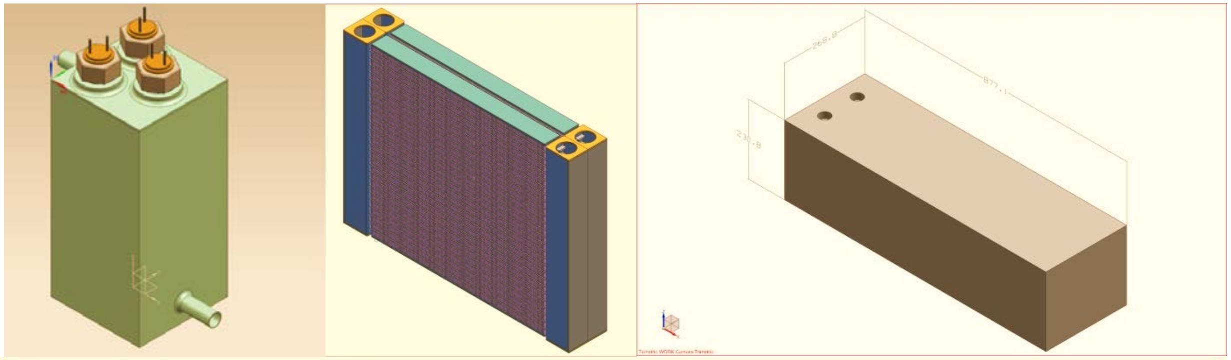


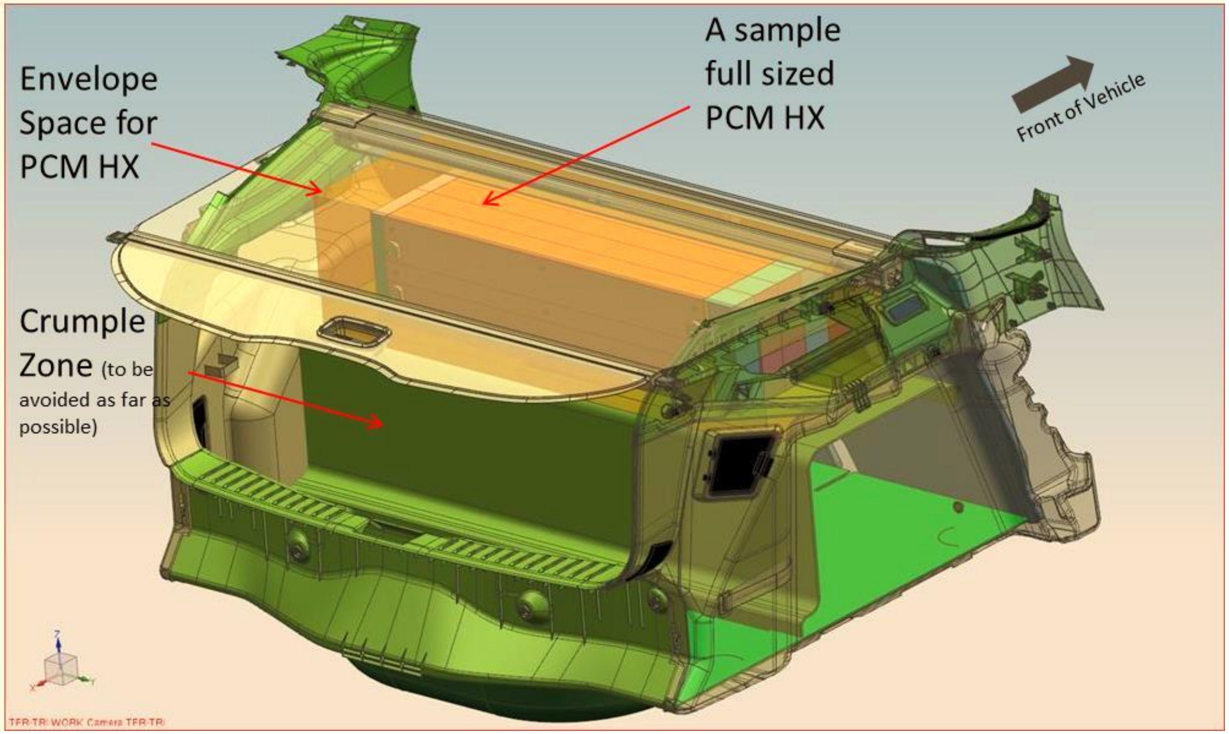
Quarter-size prototype

- 2-Pass Coolant-to-PCM heat exchanger *similar* to automotive radiator
- A quarter-size prototype will be used to characterize Coolant-to-PCM heat exchange process

Technical Accomplishments and Progress
Balance of Components and Packaging Design

- Pump and valves selected
- CapHX redesigned for ePATHS application
- Insulation prototype design completed
- Based on Ford Teamcenter vehicle design math data for Ford Focus Electric, PCM HX packaging studies completed





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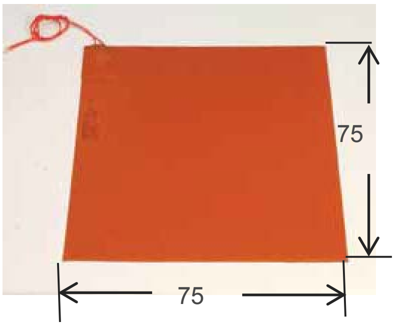
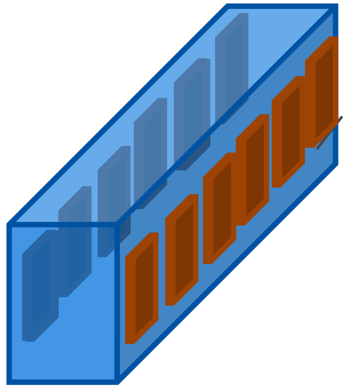
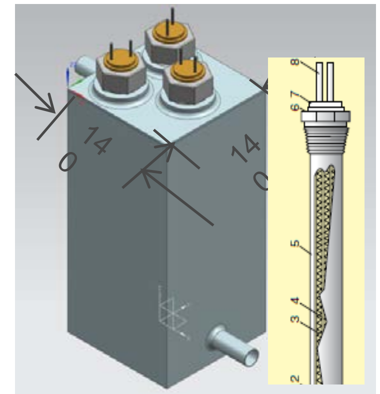
Technical Accomplishments and Progress

Charging Heater Concept Selection

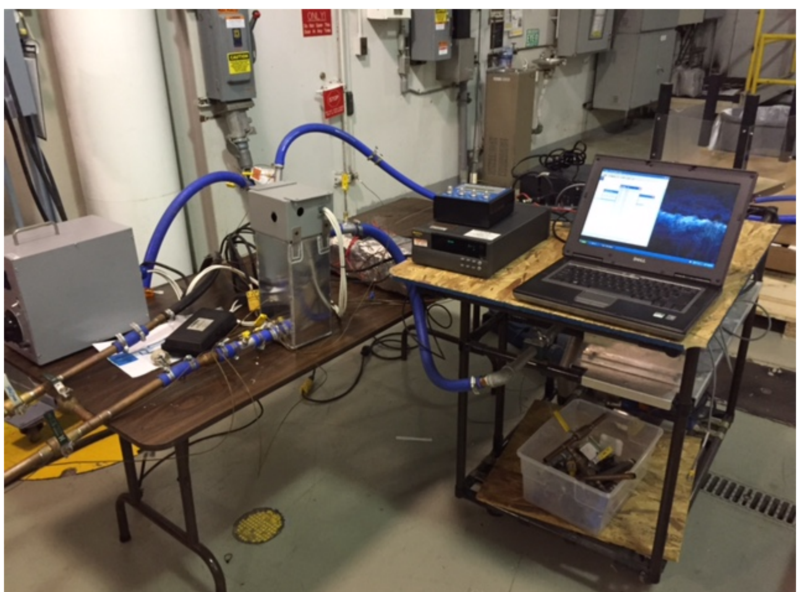


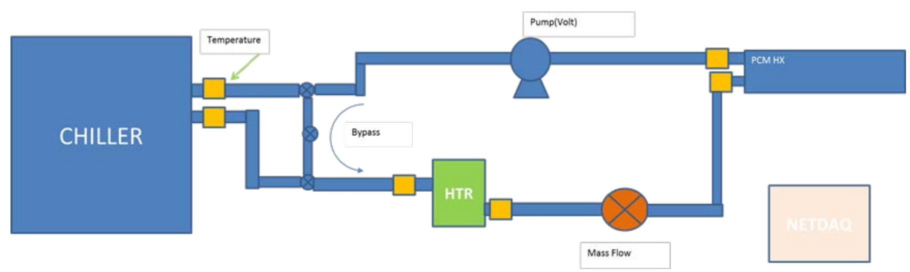
Surface Heaters





Glow Plug Heater





Testing indicates surface heater within insulation container is the most effective PCM charging method

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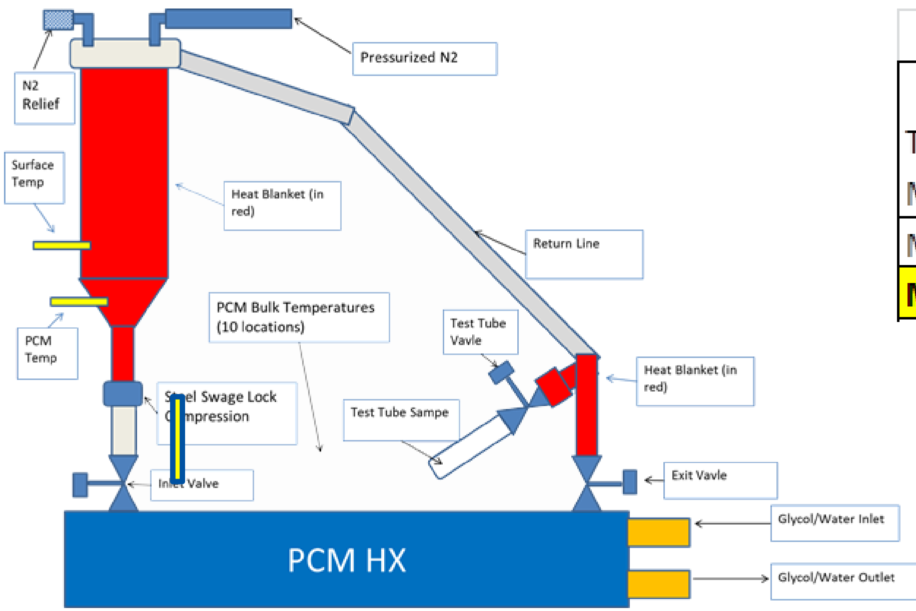
Technical Accomplishments and Progress
PCM Filling Apparatus and Test



	DV101	DPT 68	
Total HX + PCM Mass(minus valves)	8.32	8.466	kg
Mass HX	3.36	3.36	kg
Mass PCM	**4.96**	**5.106**	**kg**

Achieved Target Fill

- A filling system is designed to test-fill prototype PCM HX
  - Heating PCM to liquid state in hopper
  - Providing isolation from air and moisture
  - Maintain PCM HX at 120 °C
- Complete PCM HX filling was achieved

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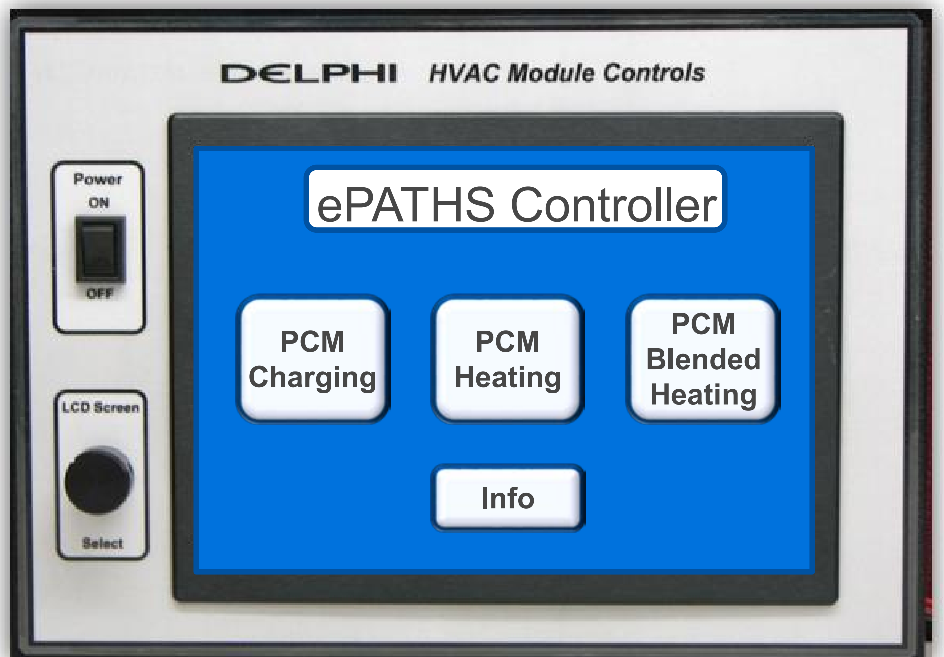
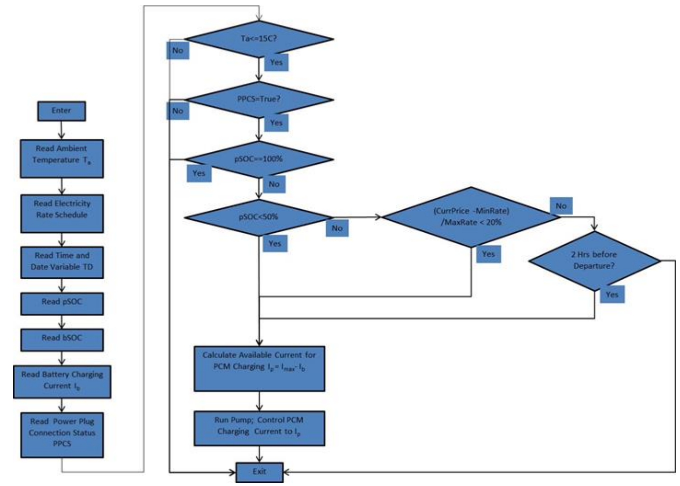
Technical Accomplishments and Progress

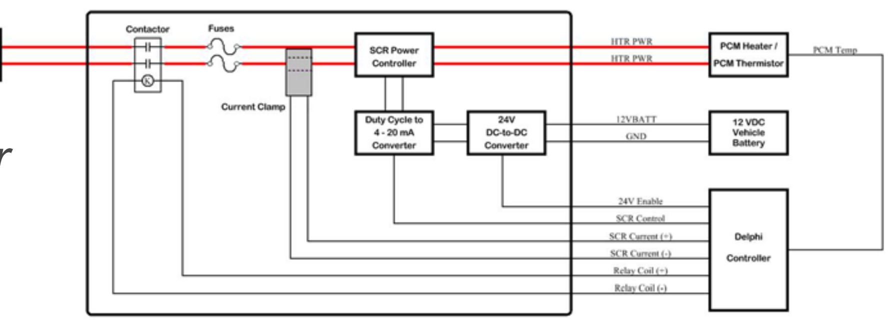
Control System Design and Development





Initial Controls Design Complete

- CAN bus communication access
  - *Ford provided access protocol for Focus Electric*
- Charging hardware interface
- Optimal charging algorithm
- Custom HVAC controller



Technical Accomplishments and Progress
PCM Materials Development: Renewable Alternatives

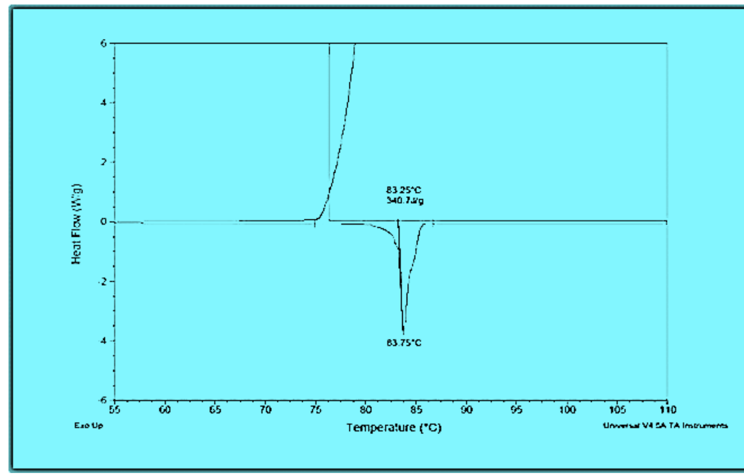
Objectives

- Development of PCMs that undergo a phase change near 85 °C (vs. 90–100 °C)
- PCM with high latent heat (350 J/g)
- PCM thermally stable and able to withstand multiple (>1000) heating and cooling cycles.

PCM	Melting Point (°C)	Latent Heat (J/g)
DPT -12	-12	267
DPT 14	14	298
DPT 23	23	335
DPT 38	38	320
DPT 50	50	343
DPT 68	68	342
DPT 83	83	340
DPT 86	86	321

BP1 Accomplishments and Progress

- Investigated 5 families of PCM candidates
- Measured the phase change temperatures, latent heats, and thermal cycling properties of these families
- Identified two possible PCMs that approach our target goals
- DPT 86 °C has a latent heat of 321 J/g
- DPT 83 °C has a latent heat of 340 J/g
- Special handling needed for filling



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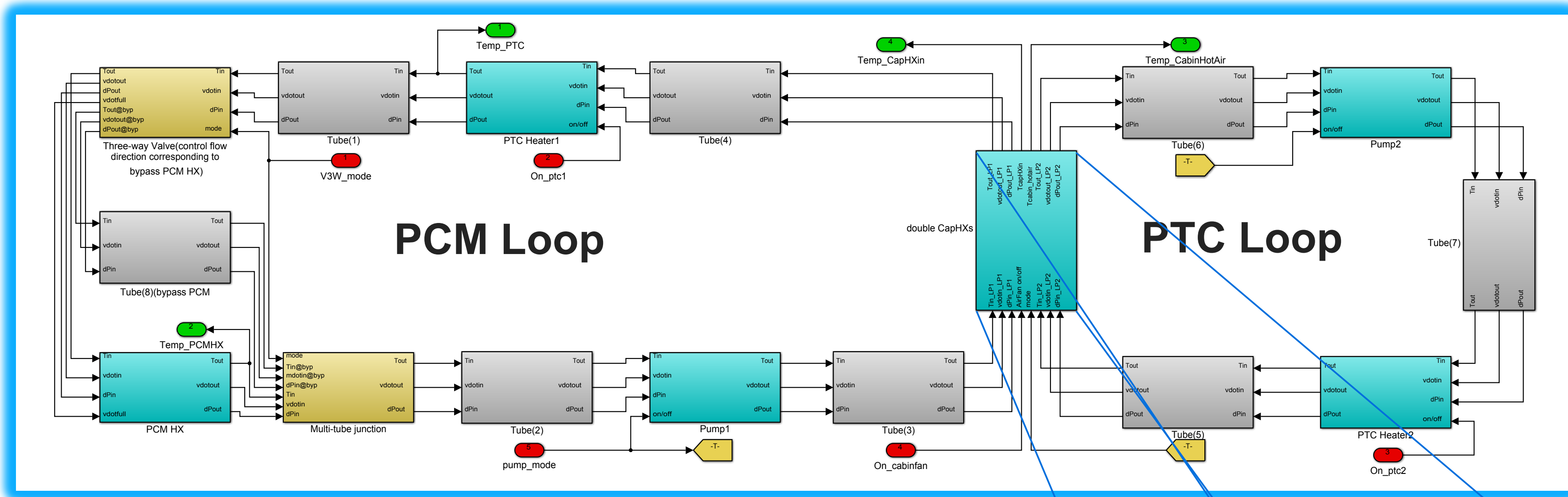
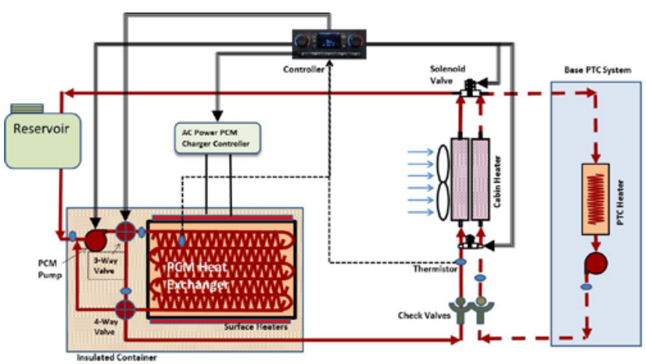
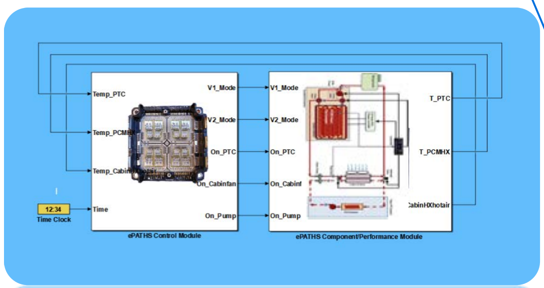
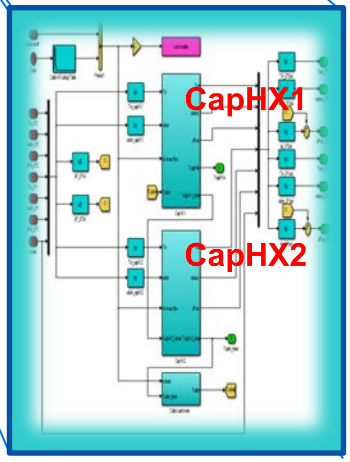
Technical Accomplishments and Progress
ORNL ePATHS System Modeling And Analysis









- Analysis of individual components and overall system performance
- Design optimization of PCM HX
- Evaluation of control strategies to achieve desired temperature control

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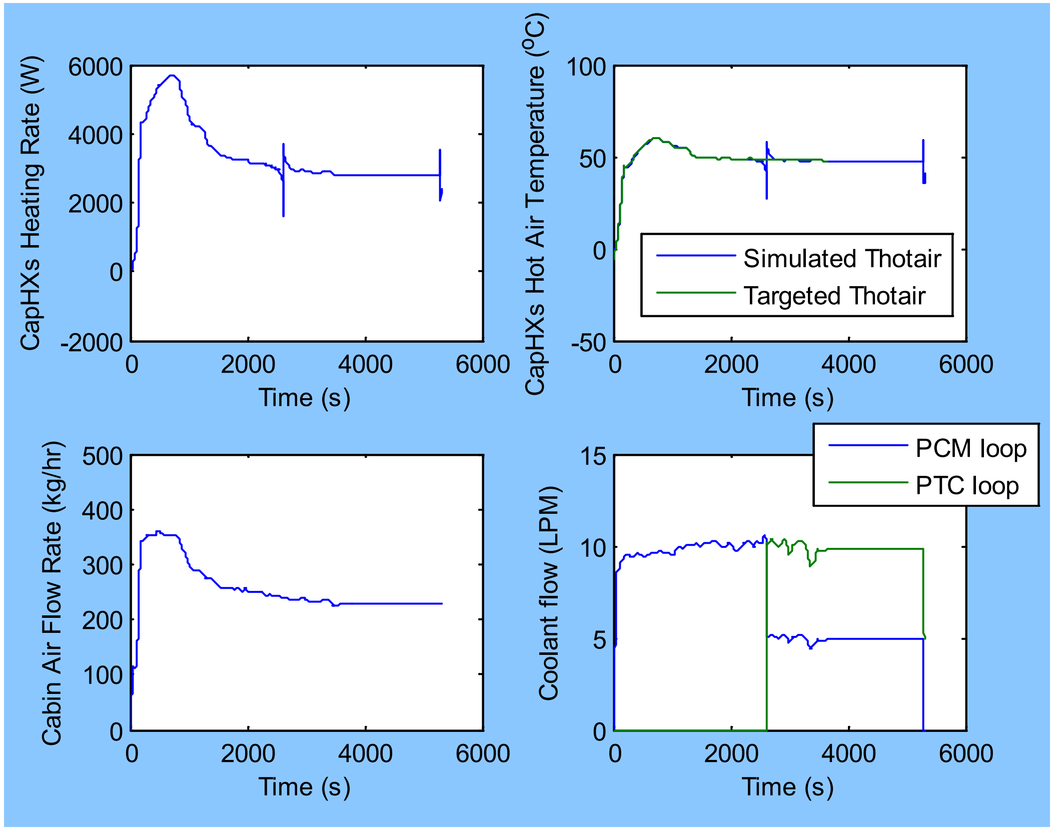
Technical Accomplishments and Progress
System Modeling and Simulation - Results

- **Air Inlet Condition:**
  - 70% ambient (-7.5 °C) and 30% cabin
  - Transient airflow profile from vehicle tests used as input
  - Maintain desired cabin air temperature at 24 °C



- **Ran mode 1 until 2600s**
  - 2.75 kWh Heating energy from PCM latent and high-temperature sensible energy
- **Ran mode 2 until 5280s**
  - 0.49 kWh Heating energy from PCM low-temperature sensible energy

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Response to Previous Year Reviewers' Comments

Comments from 2014 AMR	Response
“An argument needs to be made about the required system density, weight, and cost that if achieved, would make a compelling case over adding more battery capacity.”	The basic cost benefit analysis was presented in the original proposal to DOE. The key benefit is the low cost. We estimated that 2.7kWh heating energy will cost ~$200, Li-ion ~$650, at equivalent mass and volume. (See slide 24 for more info)
“ … the choice of extending grid-connected electric-drive vehicle (GCEV) range by greater than 20% at -10°C, is somewhat arbitrary, and has a direct influence on the benefit of this system over other competing systems as well. Perhaps, the analyses and tests should be carried over based on the duty cycles experienced by the current GCEVs in use to truly understand the trade-offs involved.”	It is accepted in the industry that winter driving can decrease electrical range by up to 50%. While PCM may be used to recover most of the range loss, an optimal target of 20% is established considering mass and volume increase. The range extension benefit will be analyzed and tested over industry accepted standards such as SAE J1634 and FTP20 driving cycle.
“… the project should use the standard connector and bypass the energy storage system in the design to provide power to the phase change material energy storage device.”	Based on reviewer and DOE managing team feedback, the system design will use J1772 connector for integrated charging.

Collaboration

- **Delphi Is Lead Organization**
  - Significant automotive experience. HVAC system, compressor, heat exchanger development expertise and global manufacturing footprints
  - Responsible for system and components design, development and vehicle integration
- **Strong Sub-Recipient Teams**
  - Ford – OEM who produces GCEV
  - ORNL – Modeling and analysis in transportation technologies
  - Entropy – Leading PCM technology and material supplier
- **Weekly Project Execution Meetings**
  - Focus on task execution and timing
  - Resolve technical and resource issues
  - Communication
- **Face to Face Technical Meetings**
  - Regular site visits and as-needed technical meetings

Proposed Future Work

- **FY15 – Technology Design and Development**
  - Task 2.1.0 – Thermal Energy Storage System Development and Demonstration – Bench Level
    - **Subtask 2.1.1 – Control System Design and Build**
    - **Subtask 2.1.2 – Preliminary Hazard Analysis**
    - **Subtask 2.1.3 – Laboratory System Performance Demonstration**
    - **Subtask 2.1.4 – Mule Vehicle Evaluation**
  - Task 2.2.0 – Commercialization Plan
    - **Subtask 2.2.1 – Initial Commercialization Plan**
- **FY16: Technology Integration and Validation**
  - Task 3.1.0 – System and Component Specification Update
  - Task 3.2.0 – System /Component Design and Development for Vehicle Integration
  - Task 3.3.0 – Vehicle Baseline Performance Measurement
  - Task 3.4.0 – Vehicle Integration of the TES
  - Task 3.5.0 – Vehicle Performance Validation Testing

Summary

- **Team Building And Collaboration**
  - Site visit for face to face discussion
  - Strong technical interactions within team
- **Vehicle Requirements And System Specification**
  - Specifications completed
- **System And Components Design Development**
  - Major components designed and prototyped
  - Minor components being procured
  - Vehicle packaging explored
- **PCM Development**
  - Five families of PCM evaluated
  - Two Candidates close to target capacity
- **System And PCM Heat Exchanger Math Model Development**
  - PCM Heat Exchanger model established
  - System model established
  - Control strategies explored
  - Climate control simulation completed

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